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Elaboration of station DICSI at KCSR and NT for studies on structural dynamics of biological objects

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Abstract

In this article, the results of the experimental and theoretical developments for equipping the station "DICSI", created on channel K1.3 (a) of the (Siberia-2) storage ring of the Kurchatov Centre for Synchrotron Radiation and Nanotechnology are considered. Argumentation for the basic parameters of the X-ray optical systems is given, photos and the schemes of created equipments are presented, in addition, the results of the test experiments with the biological objects are considered.

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Keywords: Synchrotron radiation; Polysectional system of mirrors; System of primary collimators; Densitometric curve; Collagen; Papillary muscle

1. Introduction

DICSI station has been created at the beam line (Siberia-2) of the Kurchatov Centre for Synchrotron Radiation and Nanotechnology (KCSR and NT). X-ray diffraction analysis of various native and modified human and animal tissues was systematically carried out on the station. In particular, pathologically transformed epithelial tissues such as mammary gland tumors, respiratory tracts of patients with occupational bronchial and pulmonary diseases and lung tumors, respiratory tracts of Chernobyl liquidators have been analyzed [1–3].

Versatile experiments required continuous development of specialized hardware of the station and computations for the justification of experimental parameters. In this work, the results of the following developments are presented: operative adjustments of zooms with cylindrical surfaces for focusing of the SR beam on various distances, a method for the complex adjustment of all components of the system with the optimal signal/noise ratio and recording systems of X-ray diffraction patterns of different types and using high-speed one-dimensional detector or two-coordinate recorders based on CCD-array. The results obtained on the VEPP-3 storage ring (Novosibirsk) were also used.

2. Experimental and theoretical development of the hardware of station

Fig. 1 represents the photographs of the DICSI station at the beam line K1.3 (a) of (Siberia-2) storage ring. In (A), a part of station from the beam line 1 is shown. This part includes the system of primary collimators of the SR beam 2 with focusing monochromator [4,5], the polysectional system with modular blocks of total external reflection mirrors 3 [6,7], the evacuated tube 4 passing the X-ray. In (B), the evacuated tube near the measuring complex is shown, which includes detector OD-3-1500 5 and the system of object placement and life-support 6 (for skeletal

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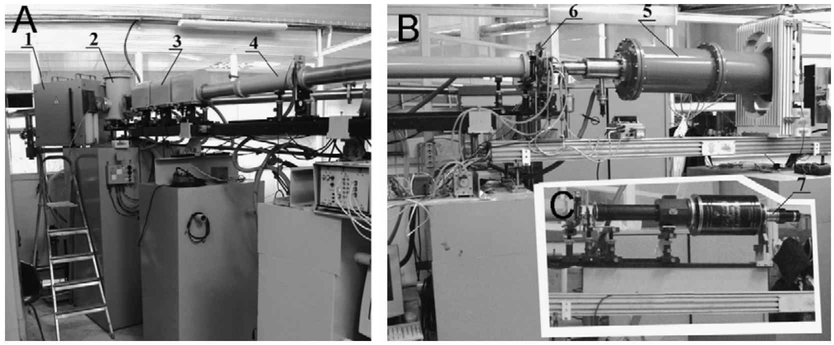

Fig. 1. Station DICSI with the measuring complex on the beam line "Siberia-2" (designations in text).

muscle) [8]. In inset (C), the registration system of X-ray diffraction images with the detector-based CCD-array 7 is displayed.

The station provides the registration of periods of 1.0–67.0 nm in the 6–12.5 keV energy range at spectral intervals of $\Delta\lambda/\lambda = 10^{-3}$–$10^{-4}$. Arrangement and configuration of focusing devices in accordance with a monochromator—mirror scheme that we proposed earlier are utilized in the X-ray optical scheme. They allow to reduce radiation and thermal loadings on a mirror and increase a relative aperture of the system [9,10]. New mechanisms for adjustment of X-ray optical elements and modernized remote control for the SR beam focusing of the system of primary collimators and the polysectional system of mirrors were created. Thus, a modular principle was adapted to the station. It allows actualizing any X-ray optical scheme for both larger angles and smaller angles of diffraction for investigations on a large variety of tasks and objects.

A photo of a modular block with the mirror of total external reflection is given in Fig. 2. Housing 6 provides an evacuated volume and has the mylar windows for input and output of the X-ray beam. This module is equipped with the manual control for angular swinging of the mirror across the SR beam and for adjustment over it. Remote control of mirror adjustment in the beam is provided by four mechanisms through vacuum-tight electrical input 5. Position 1 presents mechanism of the mirror surface flexure along the shape of a cylinder that allows formation of an image of the SR source in different focusing planes along a beam track. Position 2 presents mechanism-providing adjustment of the frontal edge of mirror in the necessary zone of the SR beam (for the first module) or on the top edge of the X-ray beam passed under previous mirror (for subsequent modules). Mechanism 3 provides the angle adjustment of mirror in the sagittal plane. Mechanism 4 provides the turn of the mirror's surface on the glancing angles.

To create the high-aperture polysectional optical system, it is necessary firstly to adjust the glancing angles of mirrors (made from different materials) in the first τ_1 and subsequently τ_n modules in accordance with boundary conditions requirements. Secondly, it is necessary to create

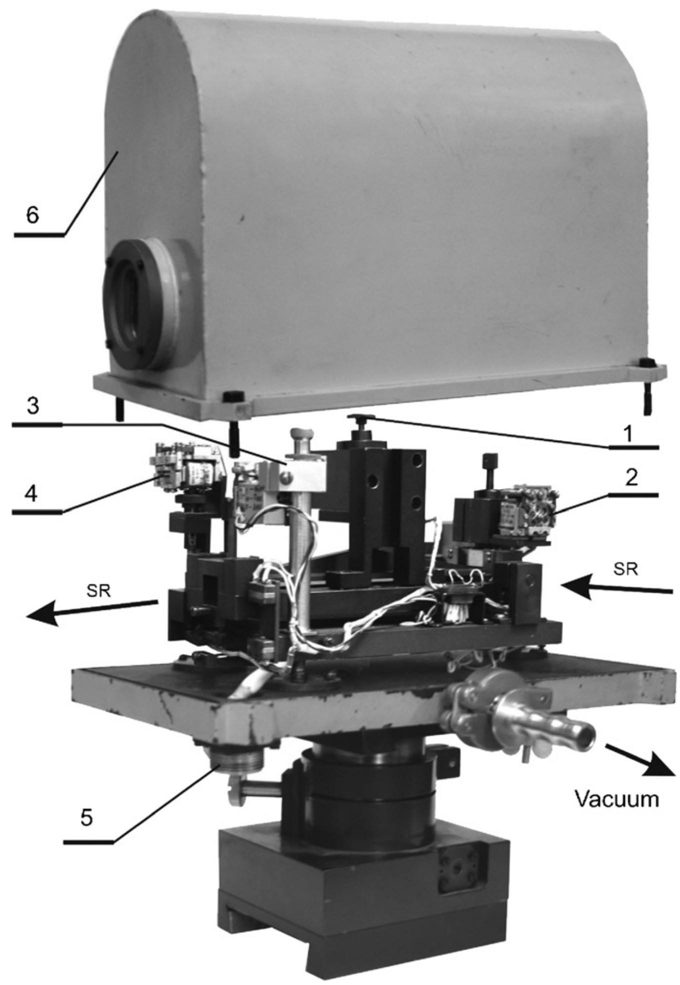

Fig. 2. Modular block with the focusing mirror (designations in text).

the optimal length of the mirror surface based on the angle-of-view field of the system ψ_n (the capture angle of the SR beam). In work [11], we have calculated these parameters by the following expressions:

$$\tau_n = 0.5\left\langle \operatorname{arctg} \frac{V_1 \sin(2\tau_1 + \psi_1) - \left\{[U_1 + (n-1)L_\tau]\operatorname{tg}\psi_n - U_1 \operatorname{tg}\psi_1\right\}}{V_1 \cos(2\tau_1 + \psi_1) - (n-1)L_\tau} - \psi_n \right\rangle \quad (1)$$